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(71) Applicant(s)
Thales Research Ltd
(Incorporated in the United Kingdom)
Western Road, BRACKNELL, BerKS,
RG12 1RG, United Kingdom

(72) Inventor(s)
Ewan Lindsay Frazer

(74) Agent and/or Address for Service
Mewburn Ellis
York House, 23 Kingsway, LONDON,
WC2B 6HP, United Kingdom

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(54) Abstract Title
Signal processing

(57) The present invention provides a method of processing a signal including a plurality of spectral components, including the steps of:

i) identifying at least one first spectral component of the signal which is to be corrected; and
ii) utilising at least one of the other spectral components of the signal (eg the rest of the signal) to correct the first spectral component.

Correction may comprise replacing the first component, or weighting various components.

In this way, rather than using specific data carried by the signal to provide the information for error correction, it is the spectral components of the signal itself which facilitate correction. Application is to GPS or other broadband time-of-flight systems which have been corrupted by noise or interference.

Fig. 1
Spectral Excision Process of Impulse Response Estimator

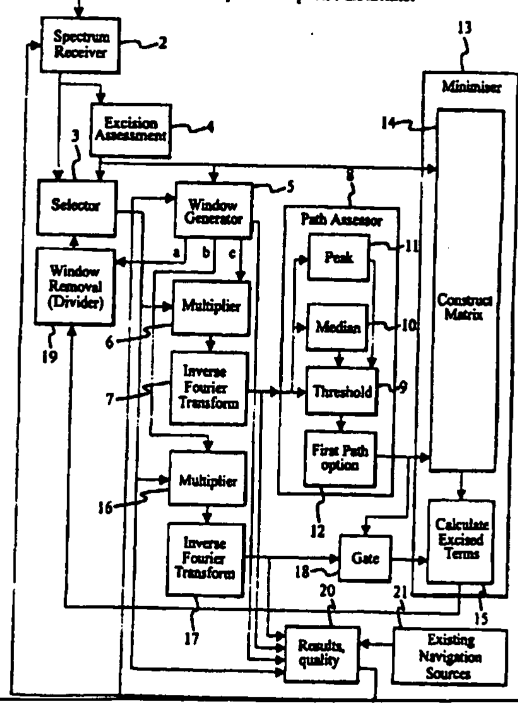

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Fig. 1
Spectral Excision Process of Impulse Response Estimator

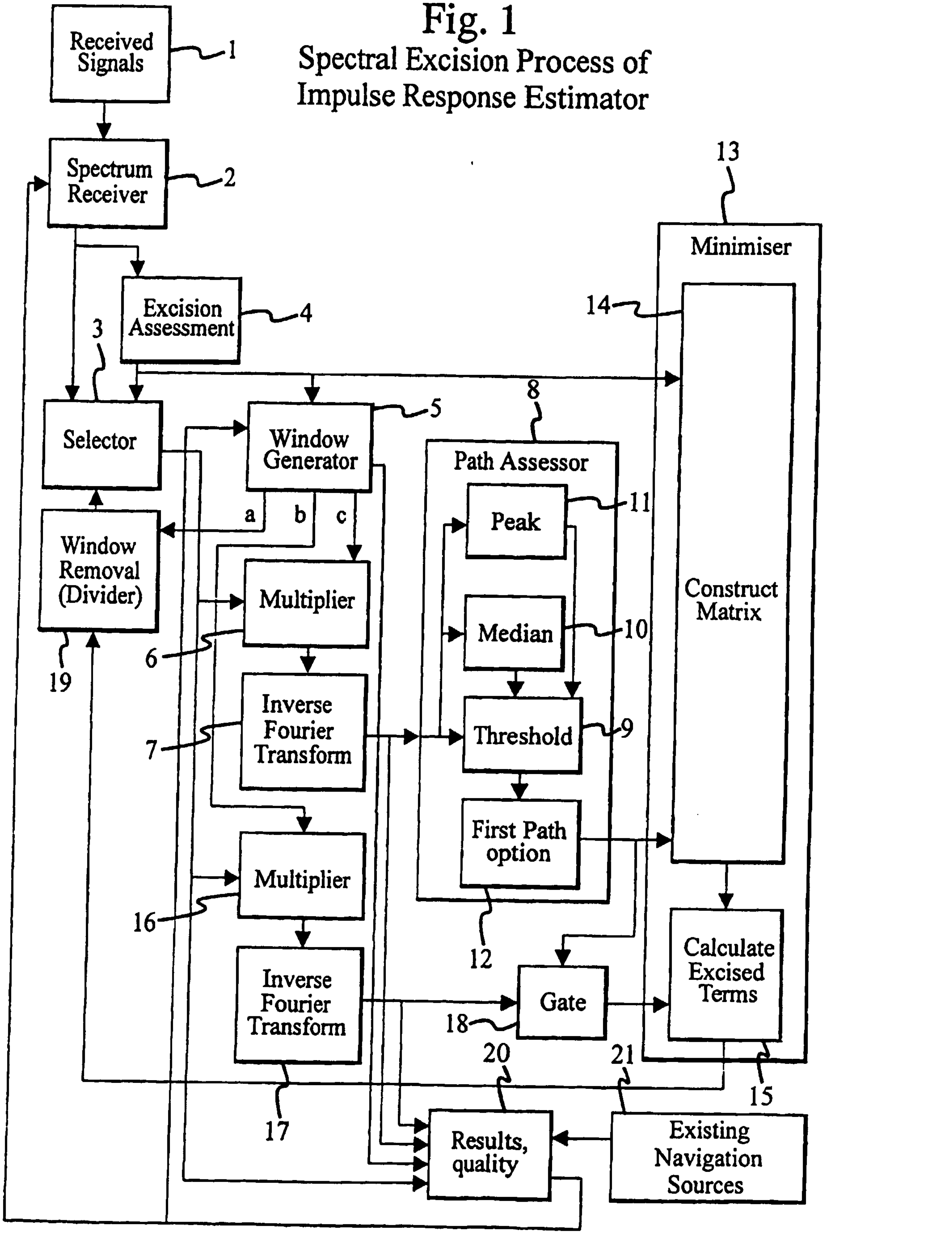


Fig. 2
Spectral Windows Applied

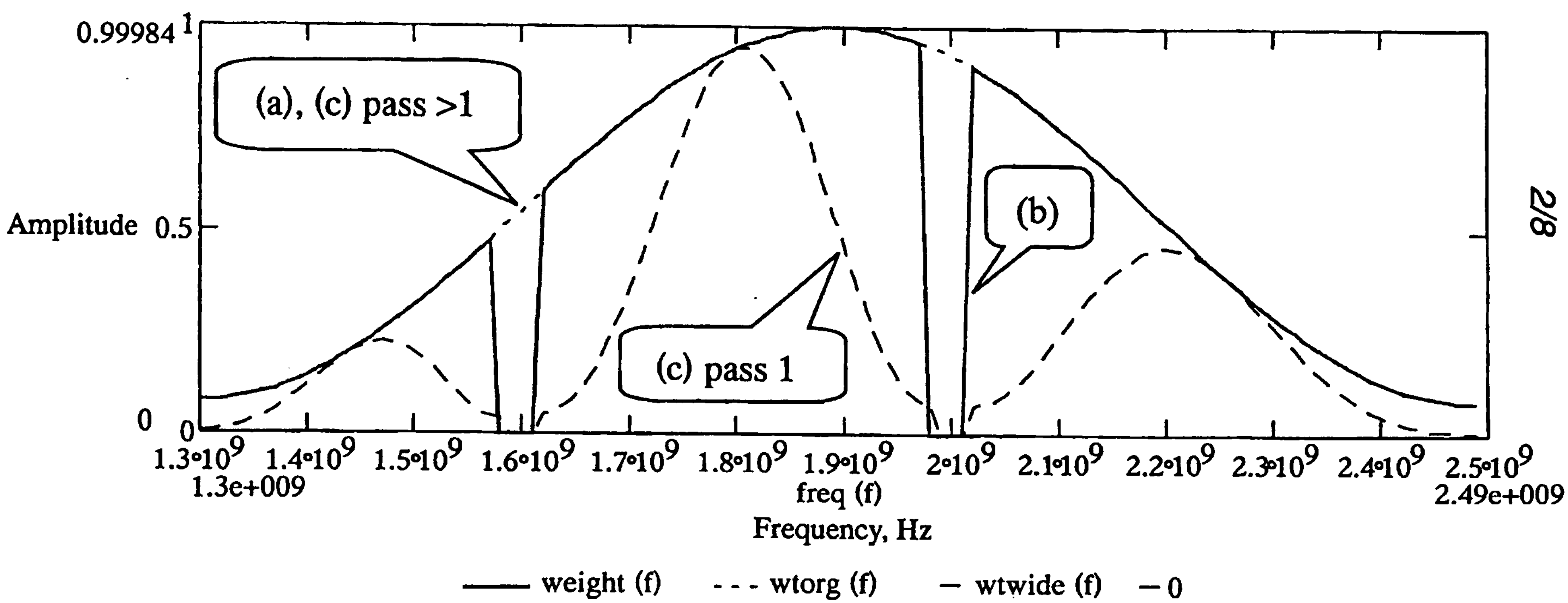


Fig. 3

Variants of Windows Used For Initial Impulse Response Estimate

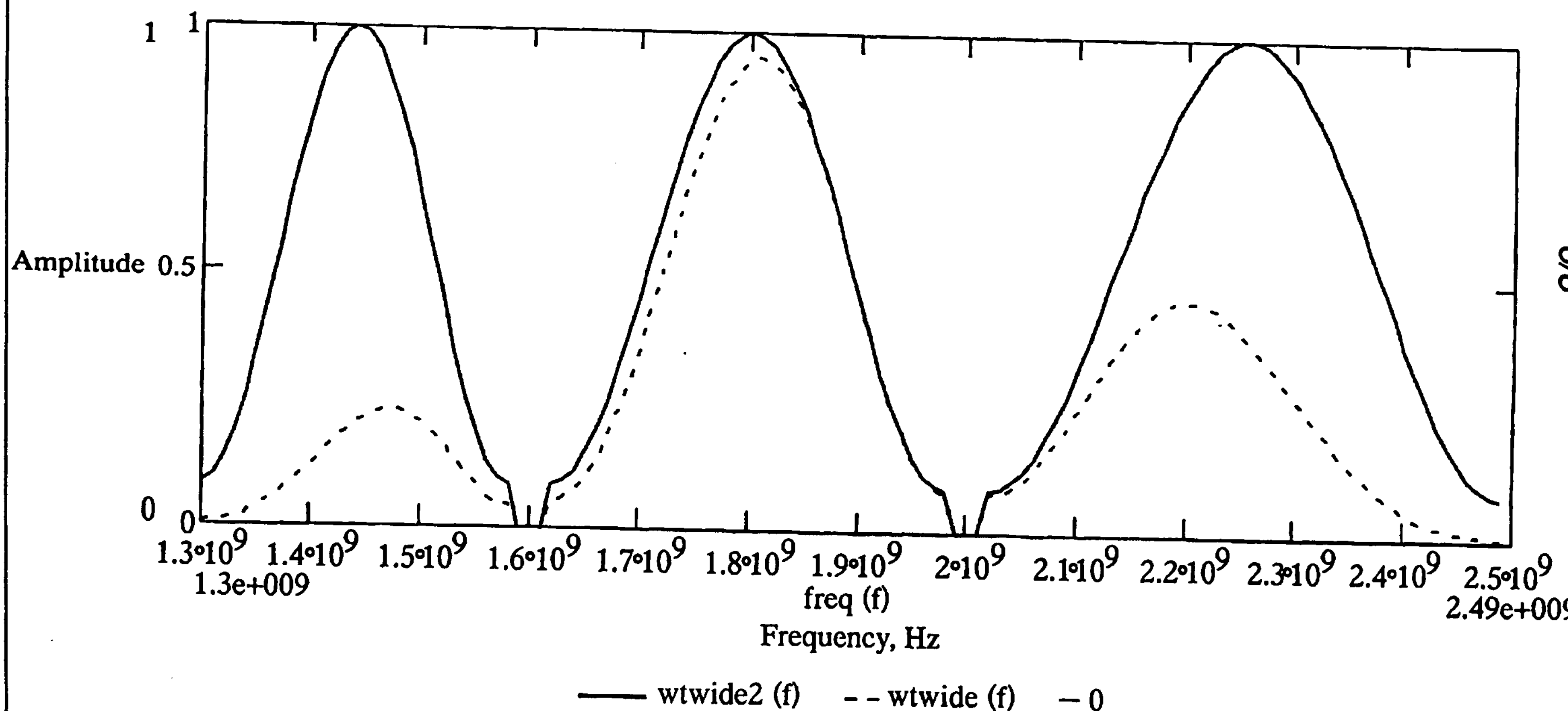
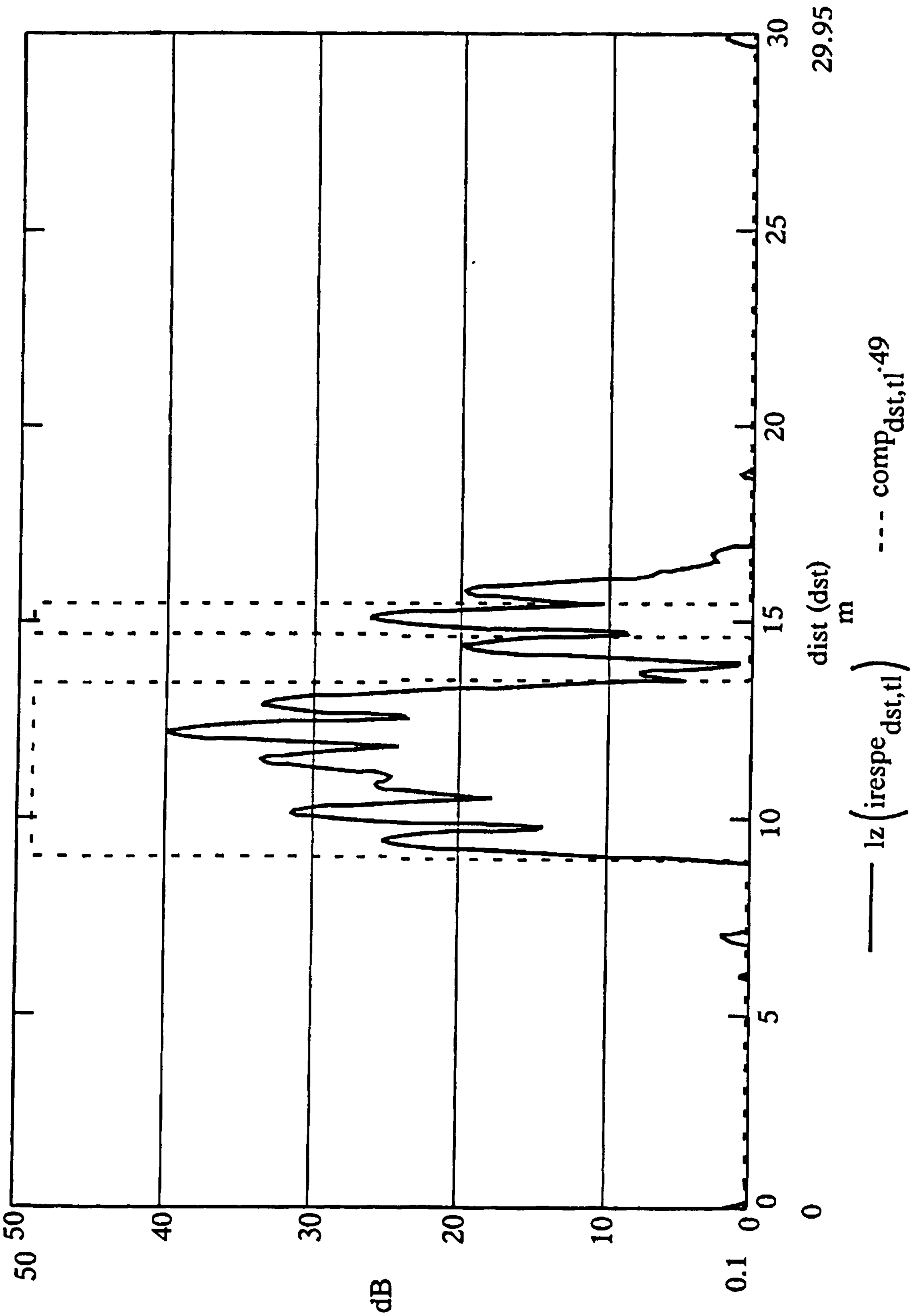


Fig. 4 Estimated Impulse Response using individual windows between notches



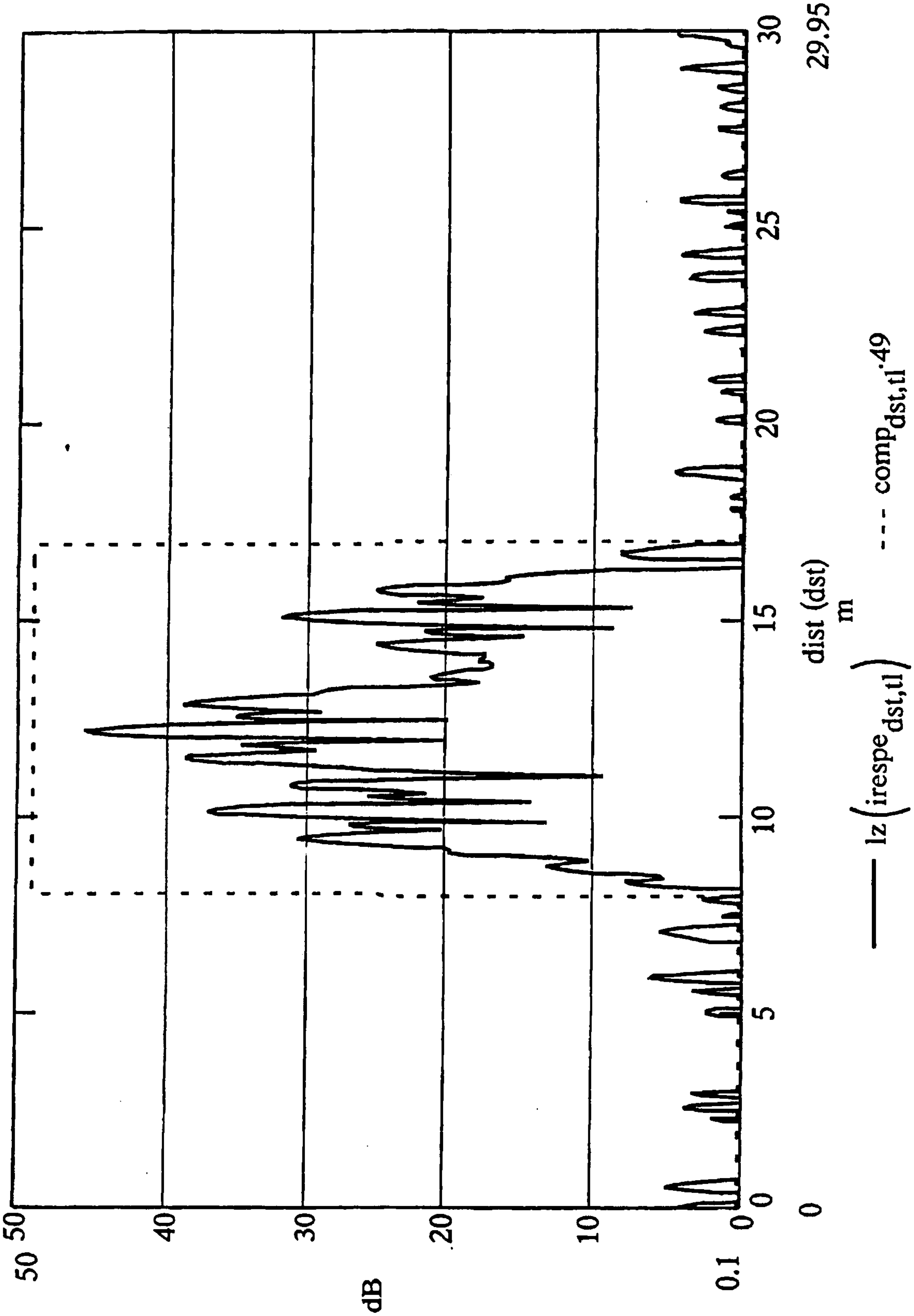


Fig. 5 Initial estimate with equal amplitude individual windows

Fig. 6 Before and after excision replacement algorithm applied

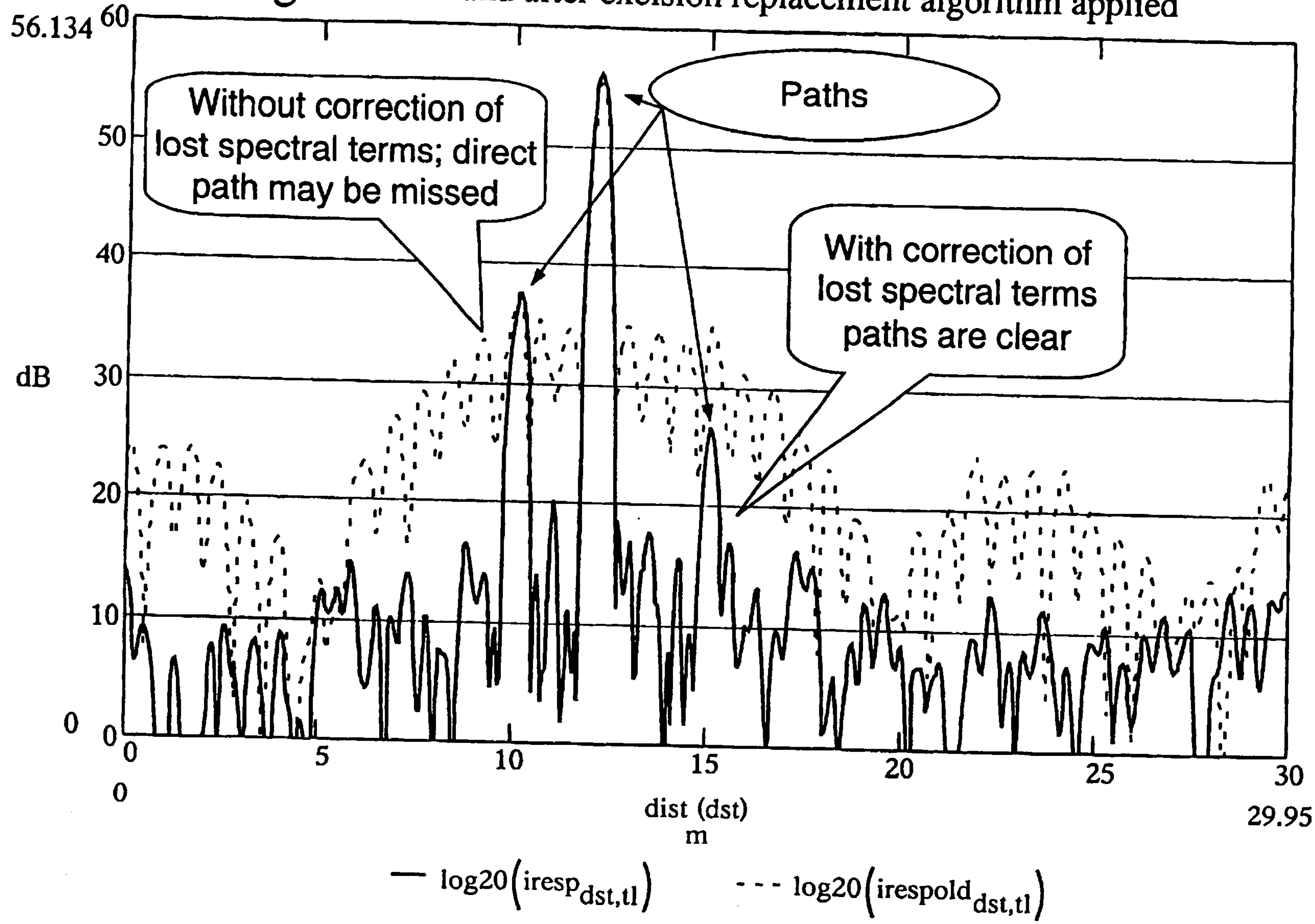


Fig. 7 DS code correlation, with multipath separated

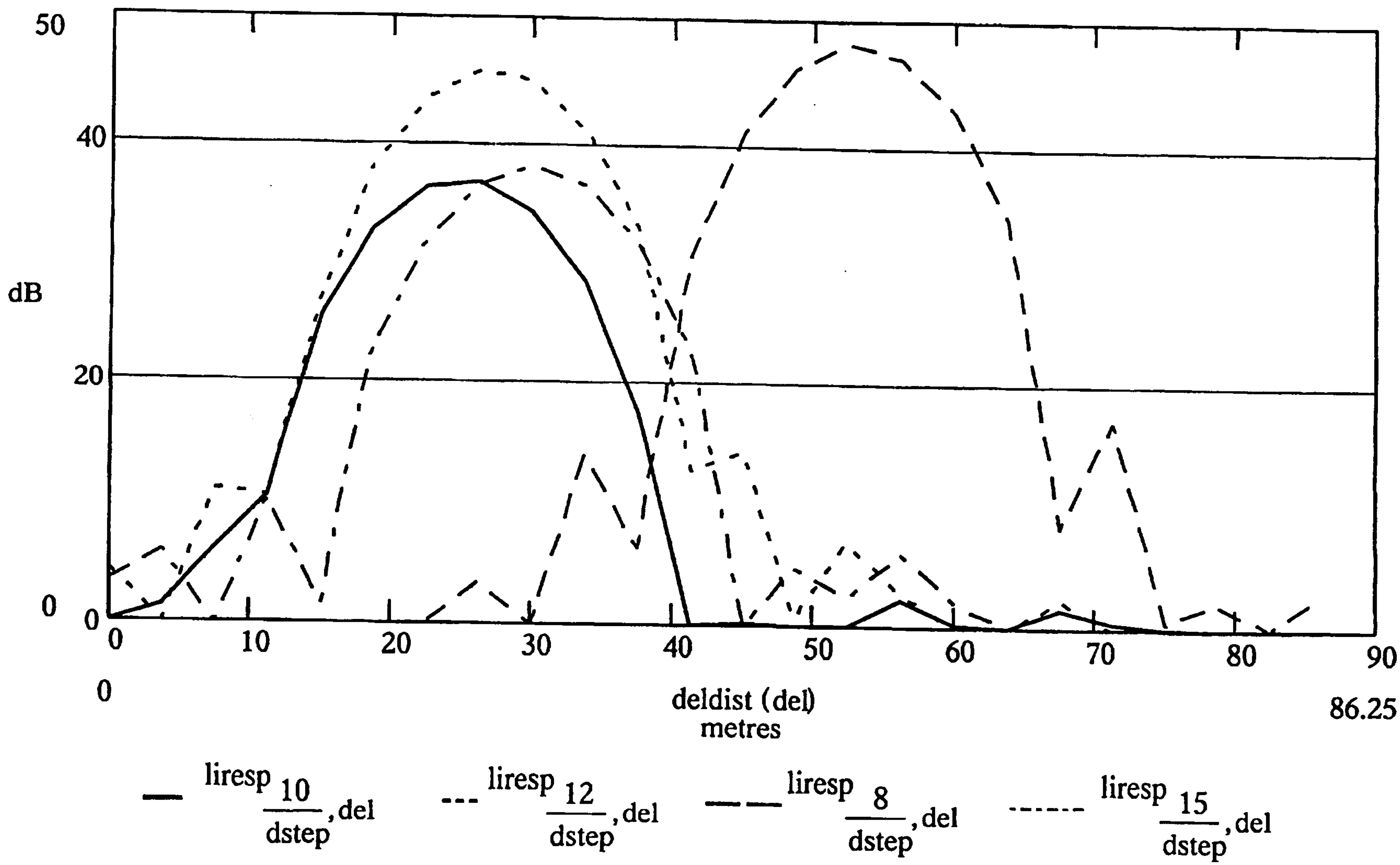
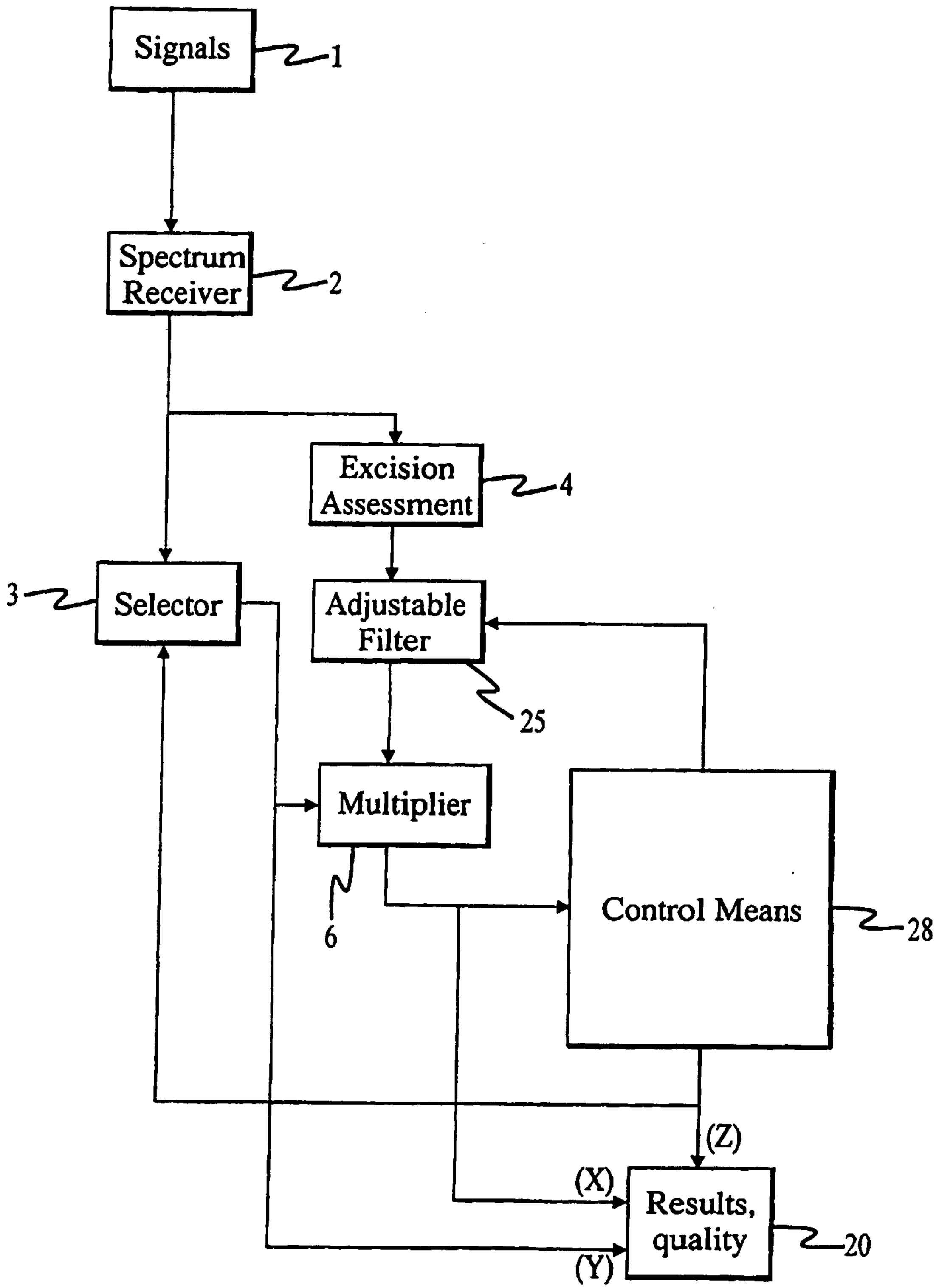


Fig. 8

Spectral Excision Process



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SIGNAL PROCESSING METHOD AND APPARATUS

The present invention relates to a method and apparatus for processing a signal. In particular, the invention relates to the processing of wideband or ultra-wideband signals and also to signals which are incomplete e.g. through being effected by interference or noise.

It is well-known of course that signals may be corrupted e.g. through interference. For wideband or ultra-wideband signals this is a particular problem since by definition such signals cover a relatively wide bandwidth and so the chance of an interfering signal occurring somewhere within that bandwidth is increased. Typical ways to try to deal with this problem have been either to try to avoid signal frequencies where interference is known to occur or to include some degree of redundancy in the data included in the signal so that if part of the signal is corrupted or lost the data can still be recovered. Both of these approaches have clear drawbacks and will not be practical in many situations. The present invention aims to address the situation in which a signal has been at least partially corrupted e.g. by interference.

Accordingly, in a first aspect, the present invention provides a method of processing a signal including a plurality of spectral components, including the steps of:

i) identifying at least one first spectral component of the signal which is to be corrected; and
ii) utilising at least one of the other spectral components of the signal to correct the first spectral component.

In this way, rather than using specific data carried by the signal to provide the information for error correction, it is the spectral components of the signal itself which facilitate correction.

As explained above, typically the spectral errors in the signal may have been caused by interference e.g. with other signals. Additionally or alternatively, interference may have been caused by the transmission of the original signal in question taking several different paths before reception, resulting in a plurality of similar signals being received. This is a particular problem with position fixing systems, such as satellite navigations systems (e.g. GPS, GLONASS, GALILEO) in which a timing signal from a satellite may travel by several different paths (e.g. due to reflection from, for example, buildings) before being received at a receiver.

Preferably the invention includes the step of removing the first spectral component(s) from the signal. This

is/are then replaced by corrected component(s) derived from at least one (and preferably some or all) of the other spectral components of the signal.

In an embodiment of the invention, after the first unwanted spectral component(s) has been removed, the signal is converted into the time domain (e.g. using an inverse Fourier transform) and the step of correcting includes reducing the energy in one or more of the time components e.g. those identified as relating to unwanted part(s) of the original signal. One way of reducing the energy in such component(s) is to weight the energy in one or more of the remaining spectral components, such as by using a least-mean-squares algorithm i.e. one in which the sum of the square of the error components is in some way reduced or minimised.

Preferably the removal and/or weighting of one or more of the spectral components of the signal is carried out using a suitable filtering process, such as using one or more sets of spectral scaling factors e.g. windows. Preferably the filter characteristics (e.g. the characteristics of the windows used as spectral scaling factors) are adjustable. For example, the characteristics may be adjusted according to the perceived characteristics of the signal (in the frequency domain) and/or according to the time domain transform spectral components. This may be done in order to improve path assessment accuracy and/or to suppress path distance and/or time components, as desired.

The number of first spectral components in the frequency domain, or the number of corresponding signal components in the time domain, may be limited e.g. to a predetermined number or to those having a predetermined characteristic or to those meeting a predetermined threshold value. For example, the characteristic may be that of amplitude and the limited number of components selected may be on the basis of those of greatest amplitude or those above a certain predetermined amplitude. Additionally or alternatively, the limited number of components selected may be on the basis of those that are perceived to contribute most to errors in the time or distance transforms.

In an embodiment where a window is applied to the signal initially in order to remove one or more unwanted spectral components, after these components have been replaced as described above the process may be repeated one or more times in order to further refine the accuracy. A different window (or other filter) may be used for one or more of the repetitions and in some examples the window (or other filter) is changed before the first repetition and, if appropriate, is further changed before each subsequent repetition.

Preferably the method includes the final step of transforming the corrected signal into the time domain so that time-of-flight or distance of flight information can be obtained for the original signal.

In some practical examples where the present invention might be used, the signal may have been created using

spreading techniques such as chirp decompression or direct sequence correlation so that the spectral components are correlated. The discrete spectral components may be more closely spaced than the original spread signal, such that there is spectral overlap. When the signal is transformed into the time domain, the time or equivalent distance range may equal or exceed the spreading chip interval (or equivalent distance) of the signal. Various techniques such as orthogonal frequency division multiplexing (OFDM) or frequency hopping may be used to provide the spectral components of the original signal. Where frequency hopping is used, the frequency hop carriers may be of equal or non-equal frequency spacing or frequency spacing which is adjusted or jittered as time progresses. The frequencies may also follow a staircase pattern or a set of staircases which repeat, and if more than one transmitter is present, one or more may transmit on each frequency one after another.

In a further aspect, the present invention provides a signal processing apparatus including (i)excision means for identifying at least one first spectral component of a signal which is to be corrected and (ii) control means for carrying out the correction by utilising one or more of the other spectral components of the signal.

The apparatus may include means for carrying and any or all of the features described herein. For example, the apparatus may include means for removing the first spectral component(s) from the signal. This is/are then replaced by corrected component(s) derived from at least

one (and preferably some or all) of the other spectral components of the signal.

In an embodiment of the invention, after the first unwanted spectral component(s) has been removed, the control means include means for converting the signal into the time domain (e.g. using an inverse Fourier transform) and reducing the energy in one or more of the time components e.g. those identified as relating to unwanted part(s) of the original signal. One way of reducing the energy in such component(s) is to weight the energy in one or more of the remaining spectral components, such as by using a least-mean-squares algorithm i.e. one in which the sum of the square of the error components is in some way reduced or minimised.

Preferably the removal and/or weighting of one or more of the spectral components of the signal is carried out using a suitable filtering means, such as using one or more sets of spectral scaling factors e.g. windows. Preferably the filter characteristics (e.g. the characteristics of the windows used as spectral scaling factors) are adjustable. For example, the characteristics may be adjusted according to the perceived characteristics of the signal (in the frequency domain) and/or according to the time domain transform spectral components. This may be done in order to improve path assessment accuracy and/or to suppress path distance and/or time components, as desired.

The number of first spectral components in the frequency domain, or the number of corresponding signal components

in the time domain, may be limited by the control means e.g. to a predetermined number or to those having a predetermined characteristic or to those meeting a predetermined threshold value. For example, the characteristic may be that of amplitude and the limited number of components selected may be on the basis of those of greatest amplitude or those above a certain predetermined amplitude. Additionally or alternatively, the limited number of components selected may be on the basis of those that are perceived to contribute most to errors in the time or distance transforms.

Embodiments of the present invention will now be described with reference to the accompanying drawings in which:

Fig. 1 is a schematic block diagram of a signal processing apparatus according to an embodiment of the present invention;

Fig. 2 is an example of several spectral windows to be applied by the window generator of Fig. 1;

Fig. 3 shows some alternative windows for use with window generator of Fig. 1;

Fig. 4 is a time domain graph of a signal which has been partially processed using the application of Fig. 1;

Fig. 5 is a time domain graph showing a signal which has been processed using different windows in the apparatus of Fig. 1;

Fig. 6 is a time domain graph showing the signal of Fig. 4 of before and after the excised turns of the signal have been replaced;

Fig. 7 shows a code correlation combined across all frequencies after excision for the signal of Fig. 6;

Fig. 8 is a schematic block diagram showing a basic system according to an embodiment of the present invention.

Fig. 8 described below is a schematic block diagram showing a basic embodiment of the invention in conceptual form. Some of the reference numerals are the same as those used for Fig. 1, where the schematic blocks related to the same functional elements.

The signal 1 to be processed is input to a spectrum receiver 2 which effectively produces a frequency domain spectrum of the signal. Based on this, excision assessment means 4 determines which spectral component(s) of the signal 1 may need to be corrected, for example because it or they have been produced or damaged by interference.

The excision assessment means 4 partially controls an adjustable filter 25 (which may be a window generator, such as item 5 in Fig. 1). The output of the spectrum receiver is then fed via a selector 3 to a multiplier 6 where it is combined with the output of the adjustable

filter 25, thereby removing those spectral component(s) determined by the excision assessment means 4.

In some examples, the output of the multiplier 6 may be suitable for use without further refinement. This is shown as input (X) to a results processor 20 in Fig. 8. More usually, further processing is required and the output of multiplier 6 is passed to control means 28.

The function of control means 28 is to replace the excised spectral term(s) using term(s) derived from one or more of the remainder of the spectral components. In some embodiments, the control means may include means for carrying out an inverse Fourier transform in order to convert the output of multiplier 6 to the time domain. Again, in some examples, the output of the means for carrying out the inverse Fourier transform may be suitable for use without further processing and this is shown as output (Z) to the results processor 20.

However, more usually, in some embodiments the control means 28 may include path assessor means for determining which portion(s) of the time domain signal may relate to unwanted spectral component(s). The control means 28 may then further include a minimiser means for reducing these unwanted term(s) and calculating replacement term(s).

The replacement term(s) are then fed to the selector 3 where they are added to the signal. On this second pass, the control means may alter the adjustable filter e.g. so that the entire signal (including the replaced term(s)) is now processed. If a frequency domain output is

required, this may be taken from selector 3 by path (Y) to the results processor 20. Alternatively, if a time domain output is required then this may be taken as before from output (Z) of the control means after the second pass through the control means.

Fig. 1 shows a schematic block diagram of an embodiment of the invention which is similar to that of Fig. 8 but which includes further preferred features.

The signals at received signals 1 contain spectral components. These will normally be (but are not restricted to) radio or radar signals of a wideband or ultra-wideband nature, and may be received from one or more sources. The reception method is often one or more antennas (for example to provide directional reception), but amongst other means could also be one or more conductive or optical links. These signals are processed at spectrum receiver 2 such that the output of spectrum receiver 2 is a set of terms representing the spectral components which change with time. These spectral components may represent, but are not limited to, components derived from a frequency hopped or orthogonal frequency division multiplex (OFDM) modulation. Spectrum receiver 2 may also receive correction information from results quality 20 and existing navigation sources 21 which allow it to adjust its timing, phase and frequency in a manner similar to many existing receiver systems. Normally spectrum receiver 2 may contain a correlative process which recovers time variant complex samples on a discrete set of frequencies, for example by correlation of direct sequence, chirp or other spread spectrum

modulation. Additionally, the spectrum receiver may filter or window the time domain signal parts prior to correlation. Where spreading codes are used, these may be chosen to be orthogonal or partly orthogonal if multiple signals are present. The spectrum receiver 2 may also calibrate itself using the received or other signals in order to reduce errors in the amplitude and/or phase of the spectral components incurred in the transmission and reception processes.

Spectrum receiver 2 may also provide a demodulation of information, for example as phase and/or amplitude shift keying; this could contain information about the source of the signals received by received signals 1, such as the location(s) of the signals.

These signals are passed to selector 3 and excision assessment 4. Selector 3 on the first pass will choose the output of spectrum receiver 2. For subsequent passes, selector 3 selects each spectral component once, but may select some from spectrum receiver 2 and some from window removal (divider)19. The choice of which representation of a spectral component is selected by selector 3 depends on the output of excision assessment 4 on the previous pass. Selector 3 chooses to select from spectrum receiver 2 for components which excision assessment 4 has identified as acceptable (not excised) on the previous pass, and selects from window removal (divider) 19 for components which were deemed by excision assessment 4 to be unacceptable on the previous pass. On the first pass selector 3 selects as if all spectral components are acceptable.

Excision assessment 4 looks at the spectral components and makes a choice as to which are likely to be acceptable and which are likely to be unacceptable. The decision process can take many forms, but will often be based on the signal energy of each component relative to the mean energy of all components. However, it can also be based on the correlative energy relative to the non-correlative energy for each spectral component, or an error or deviation measurement such as phase error on a measured signal carrier. It may also be known that the transmitter or other source of the received signals at received signals 1 has omitted certain spectral components in order to avoid creating interference.

The decision at excision assessment 4 may also choose to exclude only the worst spectral components such that a selected minimum percentage remain. The choice of this threshold percentage will usually depend on the number of spectral components and their separation, as well as the expected number of spectral components which are likely to have been damaged. For the first pass the assessment will be made as described; for subsequent passes, the result determined in the first pass will normally continue to be used. The output of excision assessment 4 is passed to window generator 5 and construct matrix 14 for this pass, and selector 3 for the next pass.

Window generator 5 creates weighting factors for the spectral components based on the output of 4. In this example there are three such weighted outputs, labelled "a", "b" and "c". These outputs are also optionally

passed to results quality 20. In its simplest form, window generator 5 will generate for output "c" a zero (or small) weighting factor for those components that are deemed unacceptable by excision assessment 4, and a constant factor (e.g. 1) for the remainder. However, it is advantageous to change the weighting of those spectral components near to those with small weightings. Another simple form of this is to increase the weightings of the nearer spectral components to those that have been reduced.

For the first pass a separate window shape can be applied between each spectral zero. For subsequent passes, a single window across all components is normally used; output "b" usually also has this form for all passes, but with zero terms at the excluded spectral components. Output "a" is a single window like output "c" on its later passes.

Typically the windows will be a Hamming or Dolph-Chebychev window shape. The quality of previous results from results quality 20 can be used to select the characteristics of the windows created by window generator 5. For example, the Dolph Chebychev main lobe to sidelobe tradeoff may be set by the level of suppression seen to be required for the multipath components. This allows the ranging accuracy to be optimised when there is minimal multipath, but allows strong multipath to be rejected at the expense of ranging accuracy when this is required. Window generator 5 passes the window weighting factors to multiplier 6 and

multiplier 16 for this pass and to window removal (divider) 19 for the next pass.

The weightings passed to the multiplier 6 which multiplies each spectral component by its weighting. These are then passed to inverse Fourier transform 7, which performs an inverse Fourier transform to convert the spectral components to a time domain waveform (or channel impulse response). An example of the equation used in inverse Fourier transform 7 is:

$$G(d) = \sum_{f} \left(e^{j\frac{2 \cdot \pi \cdot f \cdot d}{c}} \cdot F(f) \right)$$

where:

- f is a set of discrete frequencies or a subset thereof,
- F(f) is the spectral component recovered corresponding to discrete frequency f,
- c is the speed of the signal, which will usually be close to the speed of light,
- d is the distance travelled by the signal, such that t=d/c,
- t is the time-of-flight of the signal,
- G(d) is the impulse response at distance d, and often represents multipath components.

The result is in the form of a time domain signal which in this case has been interpreted as a set of path distances of the signal.

The output of inverse Fourier transform 7 can form the final result in results quality 20, and often, with a

good choice of window in window generator 5, it will not be necessary to perform a pass using items path assessor 8, minimiser 13, multiplier 16, inverse Fourier transform 17, gate 18 and window removal (divider)19. If this is not the case, the output of inverse Fourier transform 7 is passed to path assessor 8. The purpose of path assessor 8 is to assess which time components are a genuine part of the original signal, and which are as a result of damage to the spectral components assessed in excision assessment 4. An example has been shown of how this can be achieved using threshold 9, median 10, peak 11 and first path option 12.

One method is to look for the largest component in peak 11 and set a threshold at some fraction of this (e.g. 1%), which is then applied in threshold 9, such that those signals above the threshold are considered genuine, i.e. that have originated from the wanted signal source, or are not produced as a result of corruption of spectral components. Another example is to assess a percentile of the signal levels such as the 50% percentile point (i.e. the median 10, and set a threshold at a value relative to this and apply this in threshold 9 as before. A good method is to use the larger of the outputs of median 10 and peak 11 as the threshold in 9. A similar process may be used in excision assessment 4. Optionally, first path option 12 may choose to indicate that all terms after the first detected in threshold 9 are genuine. The output of path assessor 8 and first path option 12 is therefore a representation of which time or distance terms are considered to be genuine.

The purpose of minimiser 13 is to re-construct the spectral terms which were deemed by excision assessment 4 to be damaged. Construct matrix 14 and calculate excised terms 15 are one example of how this can be done. The excision algorithm used here is one of many possible options. It is presented to show that good performance is possible, rather than as indication that it is the best algorithm available.

Excision assessment 14 constructs a matrix using the output of excision assessment 4, the list of unacceptable spectral terms, and path assessor 8 the list of non-genuine time or distance terms. Each term in the matrix is a Fourier component of the form:

$$af(d,f) = e^{j\frac{2\cdot\pi\cdot f\cdot d}{c}}$$

where c is the speed of the signal (usually the speed of light),

d is the distance travelled by the signal,

f is the frequency of the signal spectral component

This equation can also be used in its time form, rather than distance, by replacing t=d/c. Also, j may be replaced by -j; j is the square root of -1.

These correspond to the components used in inverse Fourier transform 7 and inverse Fourier transform 17, however only the terms where there is a non-genuine distance term are included and only terms where the spectral component was unacceptable are included, the associated columns (for excluded frequencies) and rows

(for excluded distances) being excluded from the matrix. The form of the matrix is:

$$A = \begin{pmatrix} af(d_0, f_0) & .. & af(d_0, f_j) \\ .. & & .. \\ af(d_i, f_0) & .. & af(d_i, f_j) \end{pmatrix}$$

The terms $d_0..di$ are the distances of the non-genuine components; this will normally be the majority of the distance or time terms. The terms $f_0..f_j$ are the frequencies of the unacceptable spectral components; this will normally be a small subset of the spectral terms.

The minimiser 13 may use the matrix equation

$$Ax = y$$

with **A** as an m-row by n-column matrix formed from the Fourier contributions to **y** for the missing spectral terms
x as an n-element column vector representing the missing correlative terms from each frequency
y as an m-element column vector representing the calculated impulse response without the excision terms.

It is readily proved that this equation has the least-mean-square pseudo-inverse solution:

$x = \left(\overline{A}^T A\right)^{-1} \overline{A}^T y$ ($\overline{A}$ is the complex conjugate of matrix A, and A^T is the transpose)

This equation will minimise the mean square energy sum in **y** by choosing **x**, which represents the excised terms to be replaced. The non-genuine terms in y are minimised in

error by selecting x. This may be used as the basis of this variant of the excision process.

Gate 18 selects the non-genuine distance or time terms from inverse Fourier transform 17 $yd_0..yd_i$ using the output of path assessor 8 to produce column vector **y**.

$$y = \begin{pmatrix} yd_0 \\ .. \\ yd_i \end{pmatrix}$$

Calculate excised terms 15 takes the matrix A from construct matrix 14, the non-genuine distance (or time) terms **y** from gate 18 and produces the column vector **x**, which contains the terms which are used to replace the spectral components $xf_0..xf_j$ deemed to be unacceptable by excision assessment 4.

$$x = \begin{pmatrix} xf_0 \\ .. \\ xf_j \end{pmatrix}$$

Window removal (divider) 19 takes the spectral components calculated in calculate excised terms 15 and removes the windowing (by division of each component by the associated window coefficient) which would have been applied by window generator 5 and multiplier 16, resulting in an estimate of the spectral components that would have been produced by spectrum receiver 2 if the components had not been damaged, removed or omitted.

These are then used as replacements for the damaged spectral components in spectrum receiver 2 by selector 3.

Because multiplier 16 and inverse Fourier transform 17 perform the same function as multiplier 6 and inverse Fourier transform 7, but with different windows, they can be implemented by the same apparatus if storage and switching is used on the first pass. They are shown separately primarily for clarity.

In order for this solution to operate effectively, it has been desirable to exclude the rows from **A** and **y** where there is known to be a component in the impulse response likely to correspond to a genuine multipath component. The replacement spectral components are passed to window removal (divider) 19 for use in the next pass. Any number of passes may be performed; each should refine the result, since path assessor 8 will be able to make a better assessment of the genuine distance or time components.

The distance and time results passed to results quality 20 can be combined with those from other sources to improve the result. In particular, the greater the number of ranges known from signal sources located at different positions, the greater the accuracy with which the location of the receiver of the signals at received signals 1 can be estimated. Results quality 20 can also use knowledge of the windows produced in window generator 5 to improve the accuracy of its result, since the window shape defines the shape of the transformed component, allowing standard matching algorithms to be used to

detect the peak of the first time (or distance) component. The results may be used at the receiver, or in some form transmitted or transponded back to the source to provide a round-trip measurement. The results may also be combined with information from other positioning systems to provide a higher level of performance than could be achieved by one of the systems alone.

Assessment of the results also allows the receiver to track and adjust other receiver parameters such as timing or frequency error. The relative velocity, acceleration and position of the source of the transmission may also be calculated, as can the velocity, acceleration and position of reflecting objects, particularly if a network of receivers is used.

There are numerous options for spectral windowing at the window generator 5 to achieve good multipath separation.

In the examples below a simple Hamming window has been used as an illustration, but other windows are equally or better suited. For example, a low order Dolph-Chebychev window combined with a Hamming window should provide a slightly improved multipath resolution whilst maintaining a similar sidelobe level. Overlaid (i.e. with components added) low-order Dolph-Chebychev windows with different spectral start points can also be used; the result has a poorer sidelobe performance, but resolves finer multipath separations and has a slightly better noise performance than the Hamming window.

Figure 2 shows examples of the windows which can be used as the output from window generator 5. The x-axis represents frequency and the y-axis amplitude. The solid line shows two rectangular shaped excision notches, and is otherwise a single Hamming window across the spectrum (just visible under the solid line shown as a dotted line). The window with the solid line could be used as window (b). The window consisting of individual Hamming windows between the notches, which can be used for window (c) for the first pass, is also shown. These have been further windowed by the full width Hamming window. The single Hamming window shown could be used as window (a) for any pass and window (c) for passes other than the first. Windows such as these can be used at various stages of recovery of the channel response, although the number, position and width of the excision notches will vary according to the presence of interference.

Figure 3 also shows the individual windows which can be used as window (c) from window generator 5 on the first pass. The example shown has two regions where spectral components have been deemed unsuitable (at 1.6GHz and 2.0GHz). The solid line is not further windowed by the single full width window, the dotted line is. The solid line window in Figure 3 may result in more sidelobes in the calculated impulse response. Where the bandwidth of the excluded region is large and there are few instances of excision notches, then this multiple window approach is efficient. Where there are a large number of narrow regions to exclude, a window more like (b) is appropriate, although some improvement can be achieved by adjusting the weightings near to the notches.

An example of the operation of an embodiment of the invention will now be discussed. The examples below relate to a transmission with path delays of 10m, 12m, 15m, and 41m. The 41m path does not appear on many of the plots which follow; it is included as a path at distance which is a near alias of the 10m path. The system can equally be applied to other arrangements.

The initial impulse response estimate for the example of a code chip interval of a direct sequence spreading system in spectrum receiver 2 is shown in Figure 4 and Figure 5. The x-axis represents multipath distance (metres), and the y-axis is log magnitude. The sidelobes of the individual terms resulting from the multiple windowing are clear (and predictable), and are worse in Figure 5 which uses windows where each individual window peaks at 1, rather than a windowed set of windows. As a result of the sidelobes, more of the m-rows will be excluded than necessary. The simulation chooses those to exclude using the higher of the peak less a threshold (20dB), and the median plus a threshold (3dB). The dashed lines in the figures show the excluded terms. It is preferable to exclude more terms than exist, since the algorithm does not minimise the remaining terms so well if a real impulse response term is present amongst them. It is not necessary to exclude the sidelobes, and indeed in Figure 4 the terms at 14 and 16 metres have not been excluded.

It is also advisable to ensure that (a) does not contain identical columns. This will be the case provided the

sampling distance between rows "d" meets the following: $d<c/B$, where c is the speed of light and B is the hop bandwidth. This also indicates another method by which excision replacement can be achieved. If the sampling distance is chosen so that an excised frequency has the same column in (a) as a known term, then the known term can be used directly to replace the unknown excised term (possibly with window scaling). One problem with this is that it may unnecessarily limit the multipath resolution that can be achieved, unlike the pseudo-inverse approach.

When the calculated terms are used to replace those that were excised by selector 3, and a single full width window is applied during the combining process, then the impulse response will have narrow impulse peaks and should also have a low noise floor. (Figure 6 shows the calculated impulse response before (dotted line) and after (solid line) the excision terms are replaced, in both cases using the single Hamming window).

The code sampling point chosen in Fig. 6 was the best sample for path 1 (at 10 metres). Consequently, the amplitude of the term at 15m is smaller in amplitude here than path 1, even though the received power of these two terms is the same. Having better identified the terms, the algorithm can be applied again with fewer rows excluded in order to maximise the performance.

Figure 7 shows the code correlation combined across all frequencies after excision for each of the paths. The x-axis represents multipath distance and the y-axis represents log magnitude. A distance offset of 15m (one

chip) has been added so that the lobes of the first code correlations can be seen.

In these examples the excision process for each code sampling point at 4 x the chip rate is performed, but this is not needed in a receiver, since it can track the leading edge signal and therefore need perform only one code correlation when the DS spectrum is overlapped by the hopping process. For a frequency hopping system, the Fourier process (or a part of it) need only be performed once every time the hops have all been visited and only then if the excision is required to resolve excessive multipath. The excision process does not require all terms to be recalculated. A sliding window on the last hop-set's worth of terms is also possible if parallel receivers are used for each transmission, but the majority of applications should not need this.

The use of spectral overlap in the spreading results in no overlap of the transformed path components; it can be seen that the alias response between 25m and 55m is negligible in Figure 7. This allows the spectral replacement algorithm to detect the first path component more effectively, since there will be no significant alias terms from delayed components.

It is intended that variations and modifications such as would be readily apparent to the skilled person, may be made to the embodiments described herein without departing from the scope of the present invention disclosed herein.

CLAIMS

1. A method of processing a signal including a plurality of spectral components, including the steps of:

   i) identifying at least one first spectral component of the signal which is to be corrected; and
   ii) utilising at least one of the other spectral components of the signal to correct the first spectral component.

2. A method according to Claim 1 including the step of removing the first spectral component(s) from the signal.

3. A method according to Claim 2 including the step of replacing the first spectral component(s) by corrected component(s) derived from at least one of the other spectral components of the signal.

4. A method according to Claim 2, wherein after the first spectral component(s) has been removed, the signal is converted into the time domain and the step of correcting includes reducing the energy in one or more of the time components.

5. A method according to Claim 4 in which the energy in one or more of the time component(s) is reduced by weighting the energy in one or more of the remaining spectral components.

6. A method according to Claim 5 including using a least-mean-squares algorithm to set or weight the energy and/or phase of the one or more spectral components.

7. A method according to any of claims 2-6 wherein the removal and/or weighting of one or more of the spectral components of the signal is carried out using a suitable filtering process.

8. A method according to Claim 7 wherein the filtering process uses one or more sets of spectral scaling factors.

9. A method according to Claim 7 or Claim 8 wherein the filtering process characteristics are adjustable.

10. A method according to any of the above claims wherein the number of first spectral components in the frequency domain, or the number of corresponding signal components in the time domain, is limited.

11. A method according to any of the above claims including a final step of transforming the corrected signal into the time domain so that time-of-flight or distance of flight information can be obtained for the original signal.

12. A signal processing apparatus including (i)excision means for identifying at least one first spectral component of a signal which is to be corrected and (ii) control means for carrying out the correction by

utilising one or more of the other spectral components of the signal.

13. Apparatus according to Claim 12 including means for removing the first spectral component(s) from the signal.

14. Apparatus according to Claim 13 wherein the removed spectral component(s) is/are then replaced by corrected component(s) derived from at least one of the other spectral components of the signal.

15. Apparatus according to claims 12-14 wherein the control means includes means for converting the signal into the time domain and reducing the energy in one or more of the time components.

16. Apparatus according to claims 12-15 including filtering means for removing and/or weighting of one or more of the spectral components of the signal.

17. Apparatus according to Claim 16 wherein the characteristics of the filtering means are adjustable.

18. Apparatus according to claims 12-17 wherein the number of first spectral components in the frequency domain, or the number of corresponding signal components in the time domain, is limited by the control means.

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Claims searched: all

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

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Other: Online: WPI, PAJ, EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2284966A	MOTOROLA whole document	1 at least
X	GB2041701A	NIPPON TELEGRAPH & TELEPHONE whole document	1 at least
X	WO00/38180A1	ERICSSON whole document	1 at least
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